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A Dynamic Ammunition and Fuel
Resupply Module in Support
of the STAR Model

by

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

This thesis presents the structure of an ammunition and fuel resupply system for use with a detailed computer combat simulation. The logistics system is developed for a brigade-sized unit. Current logistics doctrine is addressed as background and is used as a basis for the module development. The parameters described for ammunition and fuel permit one to follow individual vehicle loads on the battlefield. General terms are used to describe vehicles and loads so that current or proposed systems may be used. A manual simulation provides an example of the use of the module and the analysis one may do with it. A brief description of the combat model which will use the logistics module is included.

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TABLE OF ABBREVIATIONS

AFARV: armored forward area rearm vehicle.

APDS-T: armor piercing discarding sabot tracer.

API: armor piercing incendiary.

ASO: ammunition supply officer.

ASP: ammunition supply point.

ATP: ammunition transfer point.

Cal: caliber.

DODAC: Department of Defense ammunition code.

GOER: eight-ton all-wheel drive cargo truck.

HE: high explosive.

HEAT-T: high explosive anti-tank tracer.

ICM: improved conventional munitions.

KM: kilometer.

MHE: materials handling equipment.

Mogas: Army motor vehicle gasoline.

MSR: main supply route.

MTSQ: mechanical time super quick fuse.

PD: point detonating fuse.

POL: petroleum, oils and lubricants.

ST: short ton (2000 pounds).

S & T: supply and transportation.

T: ton.

TOW: tube launched optically tracked wire guided anti-tank missile.

WP-T: white phosphorous tracer.

I. INTRODUCTION

One of the primary challenges facing the Army analysis community today is the evaluation of the many new systems proposed for the 1980's and beyond. The diverse system characteristics, coupled with the tactical complexity of the active defense, demand a new dimension in combat models to evaluate the interaction between these systems and their proposed tactical employment.

Existing land combat models may be classified in two categories: high resolution models representing combat at the indiviudal element level and low resolution models representing actions of aggregated units of elements. Currently, high resolution models describe combat at the battalion level and below for individual battles lasting approximately 45 minutes. The low resolution models represent combat between units of brigade size and larger over a time frame of several hours to several days. Because the low resolution models represent aggregated units, it is very difficult to evaluate the synergistic effects of the introduction or deletion of a particular system in the force structure. Thus, a requirement exists for a high resolution model capable of representing combat at unit levels higher than battalion and extending over a time period of several battles.

In response to this requirement, the U.S. Army Training and Doctrine Command is funding a research effort at the Naval Postgraduate School for development of the Simulation of Tactical Alternative Responses (STAR) model. This model will provide an enhanced capability to represent all pertinent elements of the combined arms team. In particular, up to a blue brigade versus a red division can be represented utilizing a battlefield of 1,500

to 2,000 square kilometers while maintaining element to element resolution. Operational modules currently exist to represent the two-sided play of ground direct fire elements, air and air defense elements and field artillery. Development of the communications/electronic warfare module and the limited visibility module will be completed during FY 1979.

The objective of this thesis is to develop the structure for a dynamic ammunition and fuel module for STAR. Because currently existing combat models represent the logistical function in terms of aggregated units, no precedence existed for a logistics module describing each resupply vehicle in the total combat environment.

The classical approach of formulating the logistics function as a transportation model using linear programming techniques presumes the ability to describe an objective function which may be optimized relative to a specified constraint set. For example, an objective function such as "Maximize the quantity of ammunition delivered to the combat vehicles per day" could be considered. This objective function might be suitable for the logistics function in isolation but it is not responsive to the real objective function of land combat such as "Determine the weapon system/tactical employment mix to maximize red losses and blue survivability." The purpose of STAR is to provide a model capable of describing the various facets of the land combat environment in order to focus on this latter objective function. The logistics module described in this thesis provides for the dynamic representation of one component of the total environment.

A discussion of current logistics doctrine, along with definitions of terms relating to ammunition and fuel, is given in Chapter II. The author assumed that the reader has some knowledge of Army terms and Army vehicles since this thesis is one of a series of reports defining the STAR model.

In addition to the logistics terms, the support structure for a division is described utilizing an example of the placement of support units in a brigade sector. Chapter II is concluded with a description of a logistics model developed in 1978 to parametrically evaluate various ammunition resupply alternatives [1] .

Chapter III describes the research conducted for this thesis. A significant portion of the research effort was devoted to a determination of the appropriate parameters required for representing the resupply function in STAR. The concept of a generic "box" for describing a hierarchy of ammunition configurations was developed and forms the basis for a flexible representation of ammunition resupply alternatives. The three basic elements of the ammunition and fuel networks - carriers, nodes and arcs - along with the parameters and constraints for these elements are also described in Chapter III.

Recall that the objective of the thesis is to develop a structure for dynamic representation of ammunition and fuel resupply for use in the STAR brigade-level model. This structure is demonstrated in Chapter IV through the use of a representative brigade scenario. Values of the parameters were determined from references 3 and 4 where possible. Each of the ammunition and fuel carriers are identified, as well as representative nodal times in the network. Arc (road) capacities will be dictated by input data to the STAR model and are not specifically addressed in this thesis.

Employment of the logistics module is demonstrated in Chapter V by a manual simulation of ammunition and fuel resupply to a Mechanized Infantry Battalion. The procedures illustrated by this example provide the basis for future implementation in STAR. Finally, data deficiencies are identified,

several cautions regarding the module are discussed and recommendations for further enhancement of the logistics module are provided.

II. BACKGROUND

A. CURRENT DOCTRINE

The resupply doctrine used as a basis for this thesis is that of the emerging logistics system, with emphasis on support far forward in the combat zone. For combat service support units to be effective in a wartime role, they must provide support where and when it is needed by the combat elements. The most significant change in the area of ammunition and fuel logistics is the concept of rearming and refueling as far forward in the combat zone as possible.

Each Army battalion and brigade in the field has a support area behind the combat positions called the trains. In the trains area, combat service support functions such as rearming, refueling, cooking meals and maintaining vehicles are conducted. The battalion trains are approximately five kilometers behind the company positions and the brigade trains are about twenty-five kilometers behind the company positions. The trains have to be close enough to support the combat units they serve but out of the way of direct enemy fire.

Combat supplies, particularly ammunition and fuel, are moved forward into the combat sector in stages. This thesis deals only with the last stages which include some supply point in the division area and the ultimate user at the company or battery level. Ammunition and fuel are distributed in the division area under what is called a supply point distribution system. The system requires that the user go to the appropriate supply point to get supplies.

1. Ammunition

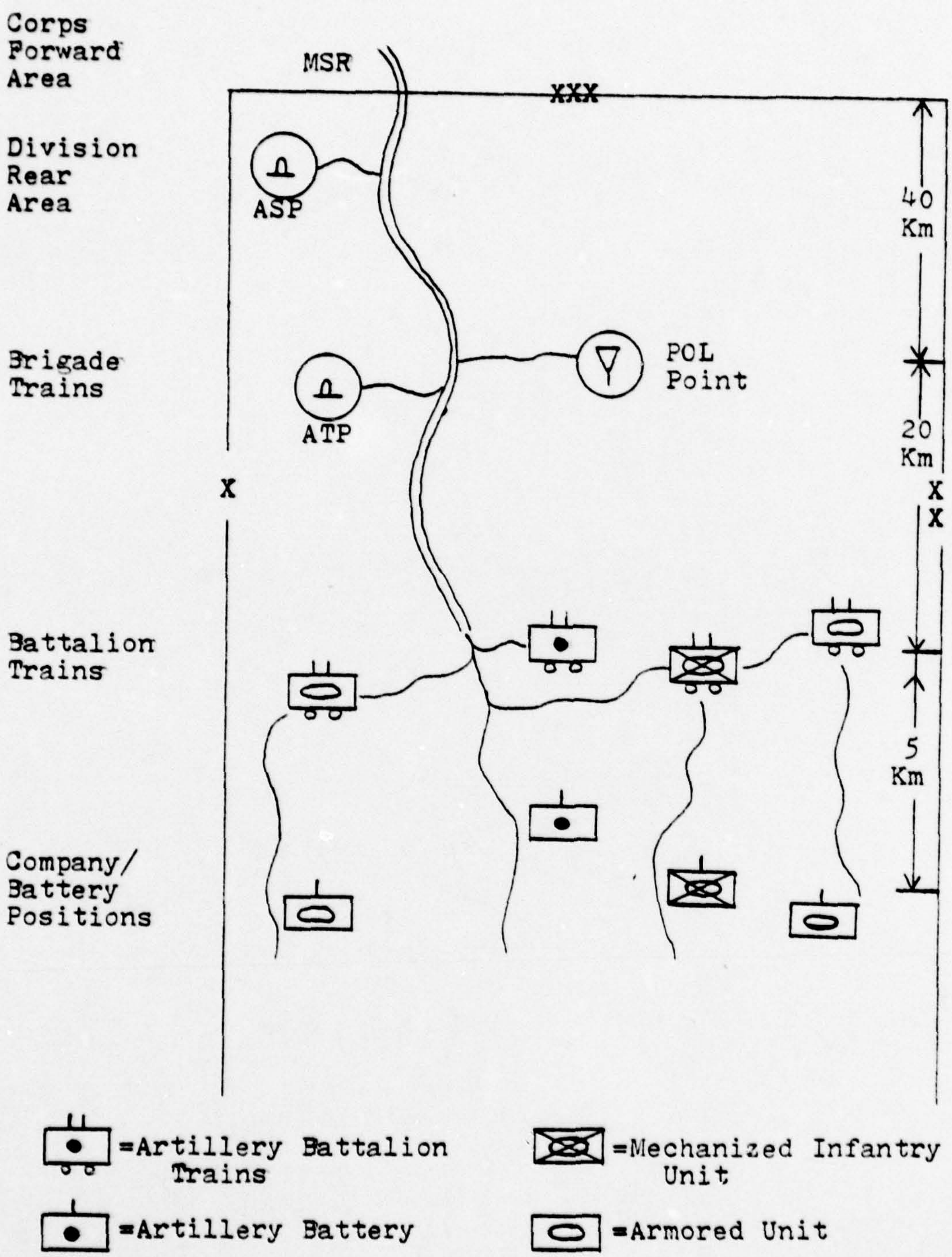
Ammunition is distributed from two types of supply points, one called an ammunition supply point (ASP) and one called an ammunition transfer point (ATP). For both the ASP and the ATP, the supply source is a larger ammunition supply point back in the corps area called the corps storage area (CSA). The CSA normally uses a throughput distribution method to resupply the ASP and the ATP. That means that the load goes directly from the CSA to its destination without being handled in between.

An ASP has the mission of stocking all types of ammunition and explosives (class V) being consumed by its supported units. The number of ASP's in support of a division can vary. The ammunition support structure now requires two conventional ammunition companies per division. Each company can operate two ASP's so a division could have as many as four supporting ASP's. Figure 1 shows a possible placement of an ASP.

Each combat brigade will also be able to obtain ammunition from an ammunition transfer point in the brigade trains area. The ATP is operated by the Supply and Service Company of the Supply and Transportation (S & T) Battalion, under the operational control of the Ammunition Supply Officer (ASO). The ATP will have materials handling equipment (MHE) to transfer pallets of ammunition from corps stake and platform trailers to unit resupply vehicles. A representative of the ASO will be present to maintain accountability records. Stockage is limited to bulky high usage items such as artillery projectiles, tank main gun ammunition and TOW missiles. Most of the stockage for the ATP will be throughput directly from the corps storage area. Additional support for the ATP is provided by the nearest ASP.

FIGURE 1

SAMPLE UNIT PLACEMENT



NOT TO SCALE

The ASP has a much greater capability than the ATP. An ammunition company has a lift capability of 2000 short tons (ST) per day. For example, a company can either issue 2000 ST or receive 1000 ST and issue 1000 ST. In contrast, an ATP can handle only 500-600 ST a day.

The battalions expending the high usage items send trucks to both the ASP and the ATP to fill all their class V needs. The advantages of the ATP operation are that some of the traffic flow is taken away from the ASP and a large volume of bulk ammunition is moved close to the combat units. A smaller number of vehicles serviced by the ASP reduces the waiting time there and at the same time reduces the tell-tale signature of the heavy traffic flow.

The most efficient packaging configuration for ammunition coming into and going out of the ASP and the ATP is on pallets. The materials handling equipment (MHE) available can load pallets onto resupply vehicles fairly quickly and all large caliber ammunition can be handled in this manner. Most ammunition rounds are packed in a box which is then placed on a pallet and banded together with an appropriate number of the same type of boxes to form the shipping unit. Obviously, for speed of handling it is desirable to maintain the palletized configuration as far forward as possible although pallets are normally taken apart in the battalion area.

The 5-ton truck with 1½-ton trailer appears to be the best choice for long distance ammunition resupply trips. The 8-ton GOER is not as well suited for highway operation since it is unstable at even moderately high speeds. The tank battalion's AFARV and the Field Artillery's M548 tracked vehicles should not be used for long distance resupply trips. They are intended for use in the battalion area.

2. Fuel

Two types of fuel are used by ground vehicles in a division, diesel fuel and mogas. Most tracked vehicles and many trucks use diesel fuel. Mogas, which is Army motor vehicle gasoline, is used in some trucks, jeeps and generators.

Diesel fuel and mogas are brought into the division area by corps tankers. From a storage area in the division support sector, tank trucks from the S & T Battalion bring fuel forward to the brigade trains area to refill unit fuel trucks. This transfer location is called the brigade petroleum, oils and lubricants (POL) point. Individual vehicles are refueled in their battalion area. A current proposal calls for equipping an armored vehicle with a fuel bladder to take fuel directly to tanks at their positions but the idea is still under study.

B. PREVIOUS WORK

The evolution of Army logistics models intended for use with a combat model is essentially in the second phase at the Naval Postgraduate School. The initial work was done by Kelley [1]. The support element modeled was the Support Platoon of a Tank Battalion. Monte Carlo techniques were used to study the effects of enemy interdiction, vehicle breakdowns, number of trips per day to the supply point, and other such factors on the total number of truckloads of ammunition delivered to the unit over a sustained period of combat. This approach allows one to investigate how the unit hauling capability is affected by the interaction of these random variables.

One aspect of this type of study is that the results are dependent on the scenario used to exercise the model and in the parameter values used during the runs. The model was built for parametric analysis independent of any particular combat model.

The combat model of interest here is the STAR model [2]. STAR is a high resolution discrete event stochastic model capable of representing individual elements on the battlefield. Parametric or digital terrain can be used to represent the battlefield. Vehicles are driven over the terrain along available routes. The primary maneuver weapon is the XM1 tank. All vehicles on the battlefield are subject to attrition from enemy fire. STAR is being developed as a complete combat model.

The next phase in modeling the logistics function during simulation of combat is to develop a system which represents all types of units involved at the same level of resolution as the combat model. In particular, in order to maintain a consistent level of detail, a supply system which can keep track of individual loads is needed for STAR. When a supply vehicle is destroyed by enemy action, the contents of that load should be deleted from play. This logistics module provides the structure to do this for the STAR brigade model.

III. DESCRIPTION OF THE MODULE

A. STRUCTURE

In the module developed in this thesis, the ammunition and POL networks consist of three basic elements: carriers, nodes and arcs.

1. Carriers

Carriers are trucks, trailers, tracked vehicles or any other such entity which can be used to transport the type of supplies being modeled. The general word carrier is used because it is not necessary that a conventional supply truck move the supplies.

Two types of carriers are represented in the module, one for ammunition and one for fuel. Within each type, there can be several subtypes with different capacities and capabilities. Ammunition carriers transport generic "boxes" of ammunition. A generic "box" is a generalization for any size package of any type of ammunition and could be a single round, a box with several rounds in it or a pallet of several boxes.

The fuel carriers transport quantities of bulk fuel of any type needed by the units the carrier is supporting. Packaged POL products are not included in this module. The actual contents of both types of carriers are specified by the user as input data.

2. Nodes

Nodes fall into two general classes: load state change nodes and travel state change nodes. Load state changes include loading, unloading and changing the configuration of the load. For example, if one transferred tank main gun ammunition from an 8-ton truck to an AFARV, the pallet on the truck would have to be taken apart, the boxes containing two rounds each would be opened and individual rounds would be loaded into the AFARV. The ASP and the ATP are also load state change nodes involving loading and unloading.

A particular "box" leaving a supply point may not arrive at a using unit in the same form. For example, a pallet of .50 caliber ammunition might be transported to the battalion trains where the pallet would be taken apart and individual boxes of ammunition would be sent forward to the companies.

Each time a state change occurs at a node, a time penalty is incurred. The time penalty may result from changing the generic "boxes," from loading or unloading, or from a traffic delay of some sort. The time penalty distribution functions must be specified by the user.

The level of resources available to accomplish a task is implicit in the time penalty assigned at a node. Loading time for ammunition is a function of the number of people and MHE available for ammunition handling. Loading time for fuel carriers is determined by the size of the carrier and the pumping rate of the servicing tank. The pumping rate is the quantity of fuel transferred per unit time, usually expressed in gallons per minute.

The other class of nodes, travel state change nodes, involve delays at choke points or road intersections where a carrier changes speed because

of a different road surface or a different level of road congestion. A choke point in the road network causes a time delay or a change in vehicle speed. It may also be a decision point regarding the route to be taken if more than one alternative route is available. Examples of choke points are a congested city or a one-lane bridge on a busy road.

3. Arcs

The third component of the networks is the arc. An arc is a road segment connecting two nodes. The road network can be considered as a capacitated network with a lower bound of zero and a finite but possibly unknown upper bound on the number of vehicles per road segment. Many different kinds of vehicles can be competing for the available road space in addition to the ammunition and POL carriers explicitly identified in this module. There might be civilians fleeing the battle area, wounded being evacuated by ambulance, disabled vehicles being towed back for repair, general supply and cargo trucks moving forward, food being delivered to the brigade and battalion trains, and possibly even combat units moving to other locations. Even though all these additional vehicles (with the exception of the combat systems) are not being played in the model at present some feature of the model should account for such additional traffic.

The more vehicles present on an arc, the slower the rate of movement will be. Therefore, the input data of travel time distributions across arcs should be adjusted to reflect the required scenario. The amount of congestion on an arc (and therefore the travel time) should be changeable by the user as the battle progresses. This will be handled in STAR in the future by controlling input data.

B. PARAMETERS

A number of parameters are necessary to identify carriers, nodes, generic "boxes," and other pertinent information. The parameters used to describe ammunition carriers are:

CC_i = carrier code for ammunition carrier i;

BN_i = battalion identification number of carrier i;

CO_i = company number of carrier i;

for $i = 1, \ldots, n_1$ ammunition carriers.

WL_{ij} = weight limit of carrier i, type j in pounds;

CL_{ij} = capacity limit of carrier i, type j in cubic feet;

for $i = 1, \ldots, n_1$ ammunition carriers;

for $j = 1, \ldots, n_2$ carrier codes for ammunition.

The parameters used to describe generic "boxes" are:

W_{kl} = weight of generic "box" kl in pounds;

C_{kl} = volume of generic "box" kl in cubic feet;

NR_{kl} = number of rounds in "box" kl;

NB_{ikl} = number of "boxes" of type kl loaded on carrier i;

for $k = 1, \ldots, n_3$ types of ammunition;

for $l = 1, \ldots, n_4$ levels of packaging.

Parameters dealing with nodal times are:

TT_m = time to travel between the entrance and exit of ammunition supply node m;

TL_{klm} = time to load one "box" of type kl at node m;

DT_m = delay time at choke point node m;

for $m = 1, \ldots, n_5$ nodes.

The parameters used to describe POL carriers are:

CCP_p = carrier code for POL carrier p;

BNP_p = battalion identification number of carrier p;

COP_p = company number of carrier p;

TF_p = type of fuel loaded on carrier p;

AF_p = amount of fuel on carrier p in gallons;

for $p = 1,\ldots,n_6$ POL carriers.

GC_q = gallon capacity of POL carrier type q;

RP_q = pumping rate of carrier type q in gallons per minute;

for $q = 1,\ldots,n_7$ carrier codes for POL.

Each ammunition carrier code has a direct relationship to the weight and volume capacity of that vehicle. The weight and volume measure of a generic "box" are used when calculating a load for a carrier to make sure the load does not exceed the weight or space limitation of the carrier. Generally, however, a load will fill all the available space before the carrier weight limit is reached.

Loading time for an ammunition carrier is assumed to be the sum of travel time inside the supply point and the time spent loading all of the "boxes." The travel time inside the supply point may be zero for some nodes. The "box" loading time may be a transfer time or an unloading time at certain nodes. In addition to the loading time at the ASP and ATP, a waiting time in a queue of ammunition carriers may cause a further delay. The STAR model keeps track of the number of vehicles waiting to be served and computes the time spent in line for each vehicle.

C. CARRIER CONSTRAINTS

Three carrier constraints must be considered. The first constraint for ammunition carriers is that the total weight of the load not exceed the weight limit of the carrier.

(1) $\sum_{k,l} W_{kl} \cdot NB_{ikl} \leq WL_{ij}$ for each i.

The second constraint for ammunition carriers is that the total volume of the cargo not exceed the space capacity of the carrier.

(2) $\sum_{k,l} C_{kl} \cdot NB_{ikl} \leq CL_{ij}$ for each i.

The constraint for a POL carrier is that the quantity of fuel in the load not exceed the capacity of the tank on the carrier.

(3) $AF_p \leq GC_p$ for each p.

IV. UTILIZATION OF THE MODULE

The previous chapter described the components of the module. An example of a brigade sector, using current doctrine and vehicles, will help to clarify each parameter and its use. For the purpose of illustration, only a few types of ammunition are represented. The vehicles designated as ammunition carriers are dedicated solely to ammunition resupply.

A. SCENARIO AND ASSUMPTIONS

Consider a brigade composed of four battalions: two Armored, one Field Artillery and one Mechanized Infantry. The placement of the units in the brigade sector is shown in Figure 2. The brigade is part of a division fighting in the European theater. The division is in a defensive posture. An ammunition network and a fuel network have been established to initiate the supply flow. The supply sources operate supply point distribution systems.

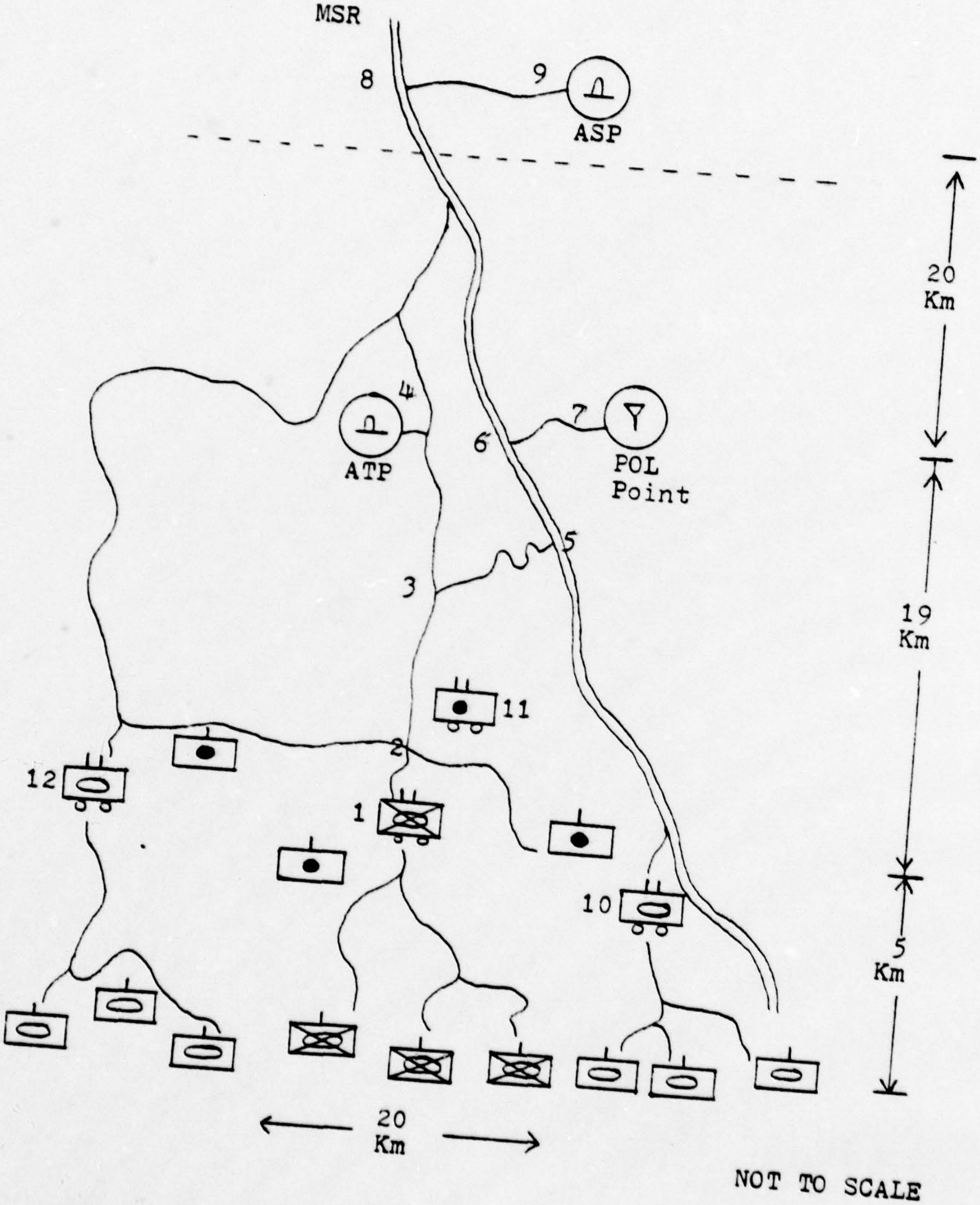
1. Network Form

The ammunition network has two source nodes, an ASP and an ATP. The relative locations of the source nodes, as well as the other ammunition nodes, are shown in Figure 3 of Appendix C.

It was assumed that all resupply vehicles start at the battalion trains. The ammunition vehicles traveled to the ASP or ATP, waited in a queue, were loaded and then waited for the rest of the vehicles from the same battalion. When the battalion convoy was ready, it started the return trip to the battalion trains. Time delays could be encountered during the

FIGURE 2

UNIT LOCATIONS



trip to or from the supply points. When the convoy reached the battalion trains, the ammunition was either transferred to company/battery vehicles or stored for later use. The sink nodes are the company/battery positions, the ultimate destination for all the ammunition in the brigade.

The POL network had one source node in the brigade trains area supplying diesel fuel and mogas. Figure 4 (Appendix C) shows the fuel distribution system. Tankers from the S & T Battalion transferred their loads to combat battalion fuel vehicles at the POL point. It was assumed that the fuel vehicles also traveled in convoys. When a battalion convoy was ready, it traveled back to the battalion trains, possibly encountering delays along the way. The battalion trains were the sink nodes for fuel. Vehicles pulled back from the front lines to the trains for refueling.

2. Movement and Loading Times

The movement and loading times were assumed to be uniformly distributed about a calculated mean value. This assumption was made to introduce some variability in the times. In STAR, the movement times will be calculated from the appropriate terrain and mobility data. The time duration was allowed to vary about the mean $\pm$ 20% following the usual continuous uniform distribution. The 20% figure was determined from analyzing terrain mobility data provided by the Army Materiel Systems Analysis Agency.

The travel times between each pair of nodes were determined by the length of the road segment and the assumed average speed of a vehicle on that type of road. The average speeds used for all vehicles, taking into account some hypothesized road congestion for this example, are given below.

TYPE ROAD	SPEED
unimproved	10 km/hr
secondary	25 km/hr
main	35 km/hr

The nodes in Figure 2 which pertain to the Mechanized Infantry Battalion example in Chapter V are described in Table I.

TABLE I: Road Network Nodes

NODE NUMBER	TYPE NODE	DESCRIPTION
1	load state change	battalion trains area
2	travel state change	road junction (choke point)
3	travel state change	small city (choke point)
4	load state change	ATP
5	travel state change	road junction (choke point)
6	travel state change	road junction
7	load state change	POL supply point
8	travel state change	road junction
9	load state change	ASP

The travel time distributions used for the Monte Carlo sampling are listed in Table II.

TABLE II: Uniform Travel Time Distributions

NODES (FROM, TO)	TIME DISTRIBUTION (MINUTES)
1,2	U(4,6)
2 delay	U(0,4)
2,3	U(5,9)
3 delay	U(3,10)

TABLE II (cont.)

NODES (FROM, TO)	TIME DISTRIBUTION (MINUTES)
3,4	U(25,33)
3,5	U(8,12)
5 delay	U(0,3)
5,6	U(16,22)
6,7	U(4,6)
5,8	U(40,50)
8,9	U(10,14)

The MHE at the ATP consisted of four cranes and/or forklifts. For simplicity of this example, the capability of each type was assumed to be the same. A 75% availability rate was assumed, leaving three pieces of MHE to service the queue. At the ASP, 24 pieces of MHE were present with 18 pieces operating at any one time. Nine pieces were assigned to offload corps storage area resupply trailers and nine units were left to service the queue of unit vehicles.

The loading time for the Mechanized Infantry Battalion 8T truck at both the ASP and ATP, using the loads specified below, was assumed to be uniformly distributed over 21 to 31 minutes.

The loading times for POL carriers were handled differently. The battalion fuel vehicles were filled from 5000 gallon tankers at the POL point. Since a number of these tankers were assumed to be there at any given time, no queue was used. This is clearly a simplification that would probably not be used in STAR. Also, the loading times were so small that a time distribution was not menaingful. The POL carriers' loading times are given below.

TYPE CARRIER	LOADING TIME(MINUTES)
truck fuel service, GOER	5
tank and pump unit	4
tank unit	2

In addition to the loading time, a five-minute paper-work processing time was assumed for each vehicle.

The operational availability of battalion ammunition and POL vehicles was assessed at the beginning of the day before the first trip. The probability that a vehicle was not operational was assumed to be 0.15. Vehicle losses due to enemy fire were not taken into account here, although that factor is present in the STAR model.

B. PARAMETER DEFINITIONS

1. Carrier Codes

Two carrier codes are used for the brigade ammunition carriers:

$j=1$ 8-ton (T) truck

$j=2$ $1\frac{1}{2}$T ammunition trailer

Three carrier codes are available for POL carriers:

$q=1$ truck fuel servicing, GOER (2500 gallons)
$q=2$ tank and pump unit (1200 gallons)
$q=3$ tank unit (600 gallons)

The first Armored Battalion had five 8T trucks for ammunition carriers. Therefore, the carrier code for ammunition carriers one through five is one. The POL carriers consisted of four GOER's (carrier code one), four tank and pump units (carrier code two), and four tank units (carrier code three). The subscripts are index numbers to keep track of how many carriers of the two types are used in the model. The battalion identification number is one. Therefore, for ammunition carriers $i=1-5$, $BN_i=1$ and for POL carriers $p=1-12$, $BNP_p=1$.

AMMUNITION CARRIERS	POL CARRIERS		
$CC_1=1$	$CCP_1=1$	$CCP_5=2$	$CCP_9=3$
$CC_2=1$	$CCP_2=1$	$CCP_6=2$	$CCP_{10}=3$
$CC_3=1$	$CCP_3=1$	$CCP_7=2$	$CCP_{11}=3$
$CC_4=1$	$CCP_4=1$	$CCP_8=2$	$CCP_{12}=3$
$CC_5=1$			

The Artillery Battalion had thirty-six ammunition carriers (i=6-41); eighteen 8T trucks (carrier code one) and eighteen 1½T trailers (carrier code two). The battalion also had four POL carriers (p=13-16); two GOER's (carrier code one), one tank and pump unit (carrier code two) and one tank unit (carrier code three). The battalion identification number is two. Therefore, for ammunition carriers i=6-41, $BN_i=2$ while for POL carriers p=13-16, $BNP_p=2$. The Artillery Battalion's vehicles are:

$CC_6=1$	$CC_{24}=2$	$CCP_{13}=1$	$CCP_{15}=2$	$CCP_{16}=3$
$CC_7=1$	$CC_{25}=2$	$CCP_{14}=1$		
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.	.			
.	.			
$CC_{23}=1$	$CC_{41}=2$			

The ammunition and POL carriers for the other battalions were identified and numbered in the same manner. A complete listing is provided in Appendix D.

2. Fuel Parameters

The type of fuel carried by the POL carriers, TF_p, was diesel for the GOER and tank and pump unit. So, for p=1-8, 13-15, 17-19 and 21-28, $TF_p=1$ which is the code for diesel fuel. The tank units all carried mogas (code two). So, for p=9-12, 16, 20 and 29-32, $TF_p=2$. The gallon capacity (GC_q) and the pumping rate (RP_q) of the POL carriers by carrier code are:

GC_1=2500 gallons	RP_1=300 gallons per minute
GC_2=1200 gallons	RP_2=100 gallons per minute
GC_3= 600 gallons	RP_3= 50 gallons per minute

The time to empty a POL carrier into one container is GC_q/RP_q, which for example is 8-1/3 minutes for the 2500 gallon GOER. Each POL carrier for this example brought the maximum amount back from the brigade refueling point. Equation (3) from Section C of Chapter III then becomes:

$$(3) \quad AF_p = GC_p \text{ for all p.}$$

3. Ammunition Parameters

The weight limit (WL_{ij}) and volume specifications (CL_{ij}) for the ammunition carriers by carrier code are:

WL_{i1}=16000 pounds	CL_{i1}=465 cubic feet
WL_{i2}= 3000 pounds	CL_{i2}= 88 cubic feet

The ammunition types and generic "boxes" selected for this example are listed in Table III. With the exception of the missiles, the data was taken from ammunition supply catalogs [3,4]. The Department of Defense Ammunition Code (DODAC) is the key to the data in the supply catalog. W_{kl} is the weight of round type k packaged at level l and C_{kl} is the volume of that "box." NR_{kl} is the number of rounds in the "box." The values of l used are:

l=1 single round;
l=2 box;
l=3 pallet.

As indicated by the data in the table, not every packaging configuration need be used by any particular scenario. Even though three levels of packing were used in this example, most types of ammunition have only two

TABLE III. Ammunition Data

DODAC, NOMENCLATURE	k	l	W_{kl} (pounds)	C_{kl} (cubic feet)	NR_{kl}
1305-A071	1	2	72	0.9	1680
5.56mm ball	1	3	3556	47.0	80640
1305-A475	2	2	68	0.7	1200
.45 cal ball					
1305-A576	3	2	75	0.9	200
.50 cal API	3	3	3700	48.0	9600
1315-C505	4	2	126	2.8	2
105mm APDS-T	4	3	1970	46.0	30
1315-C508	5	2	145	3.3	2
105mm HEAT-T	5	3	2255	54.0	30
1315-C512	6	2	137	3.0	2
105mm WP-T	6	3	2135	47.0	30
1320-D506	7	1	91	0.7	1
155mm smoke	7	3	727	6.8	8
1320-D541	8	1	30	0.8	1
155mm prop chg	8	3	1600	59.0	50
1320-D544	9	1	95	0.7	1
155mm HE	9	3	797	6.8	8
1320-D562	10	1	99	0.7	1
155mm ICM	10	3	831	6.8	8
1390-N278	11	2	55	1.0	16
fuse MTSQ					
1390-N335	12	2	55	1.0	16
fuse PD					
1390-N523	13	2	62	2.0	500
primer perc.					
1410-C594	14	1	87	4.4	1
TOW missile	14	3	1100	68.0	12
1427-C554	15	1	67	7.0	1
Dragon	15	3	1400	153.9	20

generic "boxes" in the table. This decision was made in conjunction with the decision about the types of carriers used and the load for each carrier.

4. Vehicle Load Parameters

The load for each carrier at a supply point depends on the type of supply point and on the destination of the carrier. The ATP in this example only stocked bulky high usage items, so not all types of ammunition were available at the ATP. The sample vehicle allocations between the ASP and ATP and loads by battalion are listed below in Tables IV, V and VI. NB_{ikl} is the number of "boxes" of type kl for carrier i.

The loads specified are the initial mixes for each type of unit. As the battle progresses, the user might have to change the load mixes if the ammunition expended did not closely match the ammunition delivered.

TABLE IV: Ammunition Vehicle Allocations

VEHICLE TYPE	ARMORED BATTALION	INFANTRY BATTALION	ARTILLERY BATTALION
ASP			
8T truck	2	2	0
8T truck w/1½T trailer	0	0	9
ATP			
8T truck	3	3	0
8T truck w/1½T trailer	0	0	9

The weight and volume capacity of each carrier must be considered when determining the loads. Generic "boxes" which cannot be stacked, such as projectile pallets, must also fit into the square feet of space available in the truck bed. The dimensions of the packages and the truck bed should be used when determining the loads. The volume capacity of the cargo body is really an upper bound on the amount of ammunition which could be carried.

TABLE V. Ammunition Vehicle Loads at the ATP

TYPE BATTALION	TYPE CARRIER	PACKAGE CODE, QTY	DESCRIPTION
Armored	8T truck	$NB_{i,4,3}=2$	APDS pallets
	(i=3-5,49-51)	$NB_{i,5,3}=2$	HEAT pallets
		$NB_{i,6,3}=2$	WP pallets
Artillery	8T truck	$NB_{i,9,3}=10$	HE pallets
	(i=6-14)	$NB_{i,10,3}=5$	ICM pallets
		$NB_{i,8,3}=2$	prop chg pallets
Artillery	1½T trailer	$NB_{i,8,3}=1$	prop chg pallet
	(i=24-32)	$NB_{i,9,3}=2$	HE pallets
Infantry	8T truck	$NB_{i,14,3}=2$	Dragon pallets
	(i=42-44)	$NB_{i,15,3}=2$	TOW pallets

TABLE VI. Ammunition Vehicle Loads at the ASP

TYPE BATTALION	TYPE CARRIER	PACKAGE CODE, QTY	DESCRIPTION
Armored	8T truck		
	(i=1,2,47,48)	$NB_{i,4,3}=3$	APDS pallets
		$NB_{i,5,3}=2$	HEAT pallets
		$NB_{i,3,2}=14$	.50 cal boxes
		$NB_{i,2,2}=1$	.45 cal box
Artillery	8T truck	$NB_{i,9,3}=10$	HE pallets
	(i=15-23)	$NB_{i,10,3}=2$	ICM pallets
		$NB_{i,7,3}=3$	smoke pallets
		$NB_{i,8,3}=2$	prop chg pallets
		$NB_{i,3,2}=8$	.50 cal boxes
		$NB_{i,1,2}=4$	5.56mm boxes
Artillery	1½T trailer	$NB_{i,9,3}=1$	HE pallet
	(i=33-41)	$NB_{i,8,1}=6$	prop chgs
		$NB_{i,3,2}=10$	.50 cal boxes
		$NB_{i,11,2}=8$	MTSQ fuse boxes
		$NB_{i,12,2}=8$	PD fuse boxes
		$NB_{i,13,2}=1$	box primers
Infantry	8T truck	$NB_{i,15,3}=2$	TOW pallets
	(i=45,46)	$NB_{i,1,3}=1$	5.56mm pallet
		$NB_{i,3,3}=1$	.50 cal pallet

5. Nodal Time Delays

The loading time for each ammunition carrier at a supply node was assumed to be the sum of the time used to move around inside the supply node and the total time used for loading the "boxes" on the carrier. The loading times assumed that MHE such as a forklift was available to handle pallets but that single rounds and boxes were loaded by hand. The driver and assistant driver were present to do the manual loading.

The time to travel between the entrance and exit of an ammunition supply node (TT_m) and the time to load each "box" (TL_{klm}) were estimates based on the physical layout and the resources available at each applicable node. Here, m=9 was the ASP. Based on a speed of eight kilometers per hour (5 mph) and a road network 1.33 kilometers long, TT_9=10 minutes. The ATP(m=4) had 0.8 kilometers of road so TT_4=6 minutes.

The equation for the loading time at a node m was:

$$\text{loading time} = TT_m + \sum_{k,l} (TL_{klm} \cdot NB_{ikl}) \quad \text{for each i.}$$

No MHE was available at the battalion trains area, so pallets must be taken apart and single boxes or large caliber rounds were transferred to company vehicles or stored there temporarily.

The estimated "box" loading times based on these assumptions are listed in Table VII. The subscripts in the table are:

k=type of ammunition;
l=level of packaging;
m=node number from Figure 2.

For an Armored Battalion 8T truck at the ASP, TT_9=10 minutes. For this 8T, the loading time was then:

$$10 + \left[(3 \cdot 3) + (3 \cdot 2) + (1 \cdot 14) + (1 \cdot 1) \right] = 40 \text{ minutes.}$$

TABLE VII. Ammunition Loading Times

TYPE OF ROUND	k	l	m	LOADING TIME, TL_{klm}(min.) ROUND	BOX	PALLET
5.56mm ball	1	2	9		1	
	1	3	9			3
	1	2	1		1	
.45 cal ball	2	2	9		1	
	2	2	10		1	
	2	2	12		1	
.50 cal API	3	2	9		1	
	3	3	9			3
	3	2	10		1	
	3	2	11		1	
	3	2	1		1	
	3	2	12		1	
105mm APDS-T	4	3	9			3
	4	3	4			3
	4	2	10		1	
	4	2	12		1	
105mm HEAT-T	5	3	9			3
	5	3	4			3
	5	2	10		1	
	5	2	12		1	
105mm WP-T	6	3	4			3
	6	2	10		1	
	6	2	12		1	
155mm smoke	7	3	9			2
	7	1	11	1		
155mm prop chg	8	3	9			2
	8	3	4			2
	8	1	11	1		
155mm HE	9	3	9			2
	9	3	4			2
	9	1	11	1		
155mm ICM	10	3	9			2
	10	3	4			2
	10	1	11	1		
fuse MTSQ	11	2	9		1	
	11	2	4		1	
	11	2	11		1	

TABLE VII. Continued

TYPE OF ROUND	k	l	m	LOADING TIME, TL_{klm}(min.) ROUND	BOX	PALLET
fuse PD	12	2	9		1	
	12	2	4		1	
	12	2	11		1	
primer,	13	2	4		1	
percussion	13	2	11		1	
TOW missile	14	3	9			5
	14	3	4			5
	14	1	1	3		
Dragon missile	15	3	9			5
	15	3	4			5
	15	1	1	3		

Using the same type of calculation, the loading times for the other types of vehicles are listed below.

VEHICLE	LOCATION	LOADING TIME
Armored battalion 8T	ATP	24 minutes
Artillery battalion 8T	ATP	40 "
Artillery battalion $1\frac{1}{2}$T	ATP	6 "
Artillery battalion 8T	ASP	56 "
Artillery battalion $1\frac{1}{2}$T	ASP	29 "
Infantry battalion 8T	ATP	26 "
Infantry battalion 8T	ASP	26 "

The movement time inside the supply point (TT_m) is zero for any trailers when calculating the loading time. The trailer will always be attached to another vehicle so that time should not be counted twice. The unloading or transfer time at the battalion trains area could be calculated in a similar fashion if that information were desired. For that case also, TT_m would be zero.

Three choke point nodes were identified in Figure 2 and Table 1 pertaining to the Mechanized Infantry Battalion. The delay time at a choke point was assumed to be uniformly distributed for simplicity of illustration. The assumed delay times (DT_m) used were:

NODE	DISTRIBUTION
2	U(0,4)
3	U(3,10)
5	U(0,3)

6. General

The number of subscripts of each type which have been used are:

$n_1=51$ ammunition carriers;
$n_2= 2$ types of ammunition carriers;
$n_3=15$ types of ammunition;
$n_4= 3$ levels of packaging for ammunition;
$n_5=24$ nodes if all the companies were numbered in Figure 2;
$n_6=32$ POL carriers;
$n_7= 3$ types of POL carriers.

The values assigned to the parameters are sufficient to keep track of the ammunition and POL flow for the brigade. The two main types of attrition, enemy fire and vehicle breakdowns, will reduce the number of carriers available to the units over a period of time. Deletions for these reasons or additions due to equipment replacements can be made by changing the values of the appropriate parameters.

V. BATTALION SIMULATION

A. INTRODUCTION

This chapter presents the example scenario of Chapter IV in more detail by utilizing a manual simulation of the ammunition and POL transportation of the Mechanized Infantry Battalion. A manual simulation is simplified but serves to illustrate how the logistics module will be used in STAR.

The scenario and assumptions discussed in Chapter IV are still applicable. The reader is reminded that the situation is not necessarily accurate as written due to the simplifying assumptions. However, if one were to insert empirical data, the procedures would remain the same.

Only the Mechanized Infantry Battalion was considered in this chapter although the other battalions would also be conducting resupply operations. The nodes of interest are 1-9 in Figure 2.

One round trip from the battalion trains to the ASP, ATP and the POL supply point was simulated for the appropriate vehicles. The events used during the simulation are listed in Table VIII.

TABLE VIII: List of Events in the Simulation

EVENT NUMBER	DESCRIPTION
1	departure from a checkpoint
2	arrival at a checkpoint
3	arrival at a supply node
4	vehicle joined a queue
5	vehicle began service
6	vehicle finished service
7	departure from a supply node

The battalion ammunition carriers consisted of five 8T trucks. The operational availability of each vehicle was determined by a Monte Carlo process. The results were:

TRUCK NUMBER	STATUS
CC_{42}	serviceable
CC_{43}	serviceable
CC_{44}	serviceable
CC_{45}	unserviceable
CC_{46}	serviceable

The staff supply officer decided to send two trucks to the ATP (CC_{42}, CC_{43}) and two trucks to the ASP (CC_{44}, CC_{46}).

The POL carriers consisted of two GOER's (CCP_{17}, CCP_{18}), one tank and pump unit (CCP_{19}) and one tank unit (CCP_{20}). The results of the Monte Carlo process for operational availability were:

TRUCK NUMBER	STATUS
CCP_{17}	serviceable
CCP_{18}	serviceable
CCP_{19} (with CCP_{20})	serviceable

The tank unit is a trailer pulled by the 5T truck carrying the tank and pump unit so the operational availability was not determined separately.

B. RESUPPLY CYCLE

The simulation was run manually with the resulting time sequence of events listed in Table IX. The time intervals between events were determined by sampling from the distributions in Table II. Each time resulting from the Monte Carlo process was rounded to the nearest minute to simplify the table.

TABLE IX. Time Sequence of Simulation Events

TIME	EVENT NUMBER	EVENT DESCRIPTION
0700	1	CC_{42}, CC_{43} departed for the ATP
0705	2	ATP trucks arrived at node 2
0706	1	ATP trucks departed from node 2
0710	1	CC_{44}, CC_{46} departed for the ASP
0712	2	ATP trucks arrived at node 3
0714	2	ASP trucks arrived at node 2
0715	1	ASP trucks left node 2
0717	1	ATP trucks left node 3
0720	1	POL trucks left battalion trains
0723	2	ASP trucks at node 3
0725	2	POL trucks at node 2
0726	1	ASP trucks left node 3
0728	1	POL trucks left node 2
0735	2	ASP trucks arrived at node 5
0736	1	ASP trucks left node 5
	2	POL trucks at node 3
0741	1	POL trucks left node 3
0743	3,4	ATP trucks arrived at ATP, joined queue
0752	2	POL trucks at node 5
0754	1	POL trucks left node 5
0756	5	CC_{42} began service at ATP
0813	2	POL trucks at node 6
0815	5	CC_{43} began service at ATP
0817	3,5	POL trucks arrived at supply point, began service
0825	6	CC_{42} finished service
0826	2	ASP trucks at node 8
0827	6	POL trucks loaded
0828	7	POL trucks left for battalion trains
0833	2	POL trucks at node 6
0839	6	last ATP truck loaded
	3,4	trucks arrived at ASP, joined queue
0840	7	trucks left ATP
0851	2	POL trucks at node 5
0852	1	POL trucks left node 5
0901	5	CC_{44} began service at ASP
0902	2	POL trucks at node 3
0903	5	CC_{46} began service at ASP
0906	2	ATP trucks at node 3
0912	1	POL trucks left node 3
0916	1	ATP trucks left node 3
0918	2	POL trucks at node 2
0921	6	CC_{44} loaded
	1	POL trucks left node 2
0924	2	ATP trucks at node 2
0925	1	ATP trucks left node 2

TABLE IX. Continued

TIME	EVENT NUMBER	EVENT DESCRIPTION
0925	2	POL trucks arrived at battalion trains
0929	2	ATP trucks arrived at battalion trains
0930	6	CC46 loaded
0931	7	trucks left the ASP
0942	2	ASP trucks at node 8
1023	2	ASP trucks at node 5
1024	1	ASP trucks left node 5
1034	2	ASP trucks at node 3
1041	1	ASP trucks left node 3
1049	2	ASP trucks at node 2
1050	1	ASP trucks left node 2
1054	2	ASP trucks arrived at battalion trains

From Table IX and the vehicle loads, one can see that the following supplies were delivered to the battalion trains:

TIME AVAILABLE	LOAD
0925	6200 gallons of diesel fuel 600 gallons of mogas
0929	4 pallets Dragon (80 missiles) 4 pallets TOW (48 missiles)
1054	4 pallets TOW (48 missiles) 2 pallets 5.56mm (161,280 rds) 2 pallets .50 cal (19,200 rds)

One could also simulate the movement of the company vehicles back to the battalion trains, the load transfers and the return to the company positions. When the resupply vehicles were empty, they would be available for another trip.

The battalion simulation shows how the logistics module will be used in the STAR model. All of the parameters can be specified by the user to be consistent with the situation under study. The quantity and type of loads delivered to the combat units are identifiable so a running supply status can be maintained. The logistics system operates within the context of the combat action as it should. The resupply cycle can be repeated as often as time permits, with changes to the load mix inserted by the user when necessary to keep up with the ammunition expended.

C. ANALYSIS

A sample of the analysis one will be able to do when the logistics module is operational in STAR is to consider how many battles a day the ammunition system will support. Since the road distances used in the

example were taken from the terrain box currently used in STAR and the vehicle speeds were reasonable for road travel, the times for a round trip to the ASP and the ATP can be considered to be representative of what STAR will produce. Those times were:

ROUND TRIP TO	TIME
ATP	$2\frac{1}{2}$ hours
ASP	4 hours

Consider an optimistic 24-hour period disregarding the degradation of operations during darkness, the possibility of ammunition truck attrition by enemy fire and the increased vehicle breakdowns to be expected from continuous operation. If one adds $\frac{1}{2}$-hour to unload the ammunition trucks at the battalion trains, the following number of resupply trips could be expected during the 24-hour period:

BEST CASE	LIKELY CASE
7 trips to the ATP	5 trips to the ATP
5 trips to the ASP	3 trips to the ASP

The likely case took into account the reduced movement and loading times expected during the hours of darkness. Using the same vehicle loads as stated earlier, that number of trips would result in the delivery of the following amounts of anti-tank missiles. The missiles were used here because that was the critical ammunition item in the STAR battalion battles.

BEST CASE (PER 24-HOURS)	LIKELY CASE (PER 24-HOURS)
560 Dragons	400 Dragons
576 TOW's	384 TOW's

Expenditure rates were taken from three recent STAR runs to compare the demand with the supply. The mean values determined from the three 45-minute battalion battles were:

WEAPON SYSTEM	EXPENDITURE RATE
Infantry Fighting Vehicle	4.53 TOW's/vehicle
Improved TOW Vehicle	7.20 TOW's/vehicle
Dragon team	1.41 missiles/team

These expenditure rates were only rounds fired. Some additional quantity of ammunition would be lost from at least a portion of the vehicles catastrophically killed.

For a standard Mechanized Infantry Battalion consisting of 63 Infantry Fighting Vehicles, 18 Improved TOW Vehicles and 27 Dragon teams, the expenditure rates convert to 415 TOW's and 38 Dragons per 45-minute battle. One can see immediately that a supply problem exists. Even reducing the number of Dragons and increasing the number of TOW's on the ATP ammunition trucks, only one to one and a half 45-minute battles per day can be supported. If the ammunition hauling capability was reduced at all beyond the initial availability, the situation would be even worse.

VI: DISCUSSION AND RECOMMENDATIONS

A. DISCUSSION

The logistics module structure presented in thisthesis has demonstrated a method of dynamically representing two of the most important supply commodities on the battlefield, ammunition and fuel. A high resolution combat model like STAR should have the capability to follow individual loads of supplies. Implementation of this module in STAR will provide another level of enrichment which will permit the user to gain a deeper insight into the combat process.

The carrier constraints in Chapter III do not allow for the possibility of more than one type of fuel in a carrier since the existing POL carriers are designed to hold only one type of fuel at a time (see Appendix B for a list of current single commodity fuel carriers). If the user wished to include a carrier which could hold more than one type of fuel, another subscript could be added to the parameters TF, AF and GC.

No constraints have been included here to cover the issue of explosive safety compatibility. In peacetime, strict rules are enforced regarding the mixture of different types of ammunition in storage and in transit. The rules outside the United States might be more or less stringent than our own, depending on the country involved.

Each theater has its own local regulations which comply with the more stringent criteria. However, the U.S. Army does not have a standard transportation safety guide for a Theater of Operations. In an actual

combat situation, it is not clear how much attention would be given to any mixture of ammunition in a vehicle. If the user of this module wished to include some set of guidelines, each generic "box" could be assigned to some class which would constitute another parameter. An additional constraint would have to be added to the constraint set to insure that all "boxes" on a carrier were from the same class. The impact of doing this would be a more complicated loading plan and probably some wasted space on the carriers, which in the judgment of the author is not allowed to occur in a combat situation.

The difficulty most likely to be encountered when using the module is finding the data for the required ammunition and vehicles. The weight and volume of packages of newly developed rounds are not found in the ammunition supply catalogs. A possible source for this data is the branch school sponsoring the new round. Even then, the data for individual rounds is not readily available. One method for estimating single round data would be dividing the size and weight of a box by the number of rounds included.

The cargo volume of the vehicles in the example was determined by using the height of the side of the cargo body above the bed or the height of the side rails if the vehicle had side rails. The resulting figure is an approximation of the amount of cargo space which could be used for ammunition. Individual boxes would normally not be stacked above that level but the height of a pallet could be greater than the height of the vehicle side without causing problems.

The pumping rate for fuel vehicles is generally adjustable up to a maximum depending on the size hose attached. The 600 gallon tank unit does not have a pump but rather relies on gravity discharge. The tank

unit would probably be used to refuel small items that require mogas such as stoves and generators. The size of the hose would have to be considered when determining the maximum pumping rate of the other fuel vehicles.

B. RECOMMENDATIONS

The next step in this research process would be to code this module in Simscript which is the programming language used in STAR. The data structures of Simscript provide a convenient method of assigning parameter values to the various logistics elements. The necessary queues at supply points are also accomodated by the data structures.

Another area of interest would be to examine the ammunition supply links between the corps storage area, the ASP and the ATP. This module did not address the question of sufficient stockage at the ASP and the ATP to meet the demands. An implicit assumption was made that the supply points could fill any demands they received. If that were not the case, a decision logic would have to decide what each unit would get based on such things as the quantity on hand, projected resupply and the current unit priority status.

Many possibilities exist for expanding the modeling of the logistics function both in support of a combat model and in isolation. The logistics analyst can contribute a great deal toward a better Army of the future.

APPENDIX A

CURRENT AMMUNITION VEHICLES

The following vehicles are used in an Army division as ammunition resupply vehicles or caisson vehicles. The tonnage stated is applicable for a cross-country movement. The three leading candidates for an AFARV are included since no decision had been made yet on which one will be adopted by the Army

Vehicle	Size of Cargo Compartment, LxWxH(in)	Volume Capacity for Payload(ft^3)
trailer ammunition 1½T. M332	55.4 x 68.5 x 40	88
trailer cargo 1½T, M105A2	110 x 74 x 45	212
truck cargo 2½T M35A2	147 x 88 x 36.5	273
truck cargo 5T M813	168 x 88 x 36.5	312
truck cargo 8T M520 (GOER)	195 x 97 x 42.5	465
carrier cargo tracked 6T, M548	130.6 x 96.5 x 47.5	346
AFARV candidates:		
1. M113A1 stripped personnel carrier, 1-3/5T	100.75 x 64.5 x 49.5	186

2. M113S stretched personnel carrier, $4\frac{1}{2}$T	128.25 x 64.5 x 49.5	237
3. GSRS carrier with cargo body, 10T	156 x 70 x 70	442

APPENDIX B

CURRENT BULK FUEL VEHICLES

The vehicles in an Army division at the present time, to carry diesel fuel and mogas in bulk quantities, are listed below. The pump rates depend on the size hose used and in some cases can be adjusted up to the maximum rate listed.

Vehicle	Capacity (gallons)	Pump Rate (gallons per min.)
drum, forward area refuel[1] equipment (FARE)	500	100
tank unit liquid dispensing,[2] truck mounted	600	50
tank and pump unit liquid dispensing, truck mounted	1200	100
truck tank fuel servicing, GOER	2500	300
semi-trailer tank bulk haul and fuel servicing	5000	600

[1] The FARE is similar to a trailer but does not have wheels. It is pulled behind a truck and can also be airlifted.

[2] Gravity fed, does not have a pump.

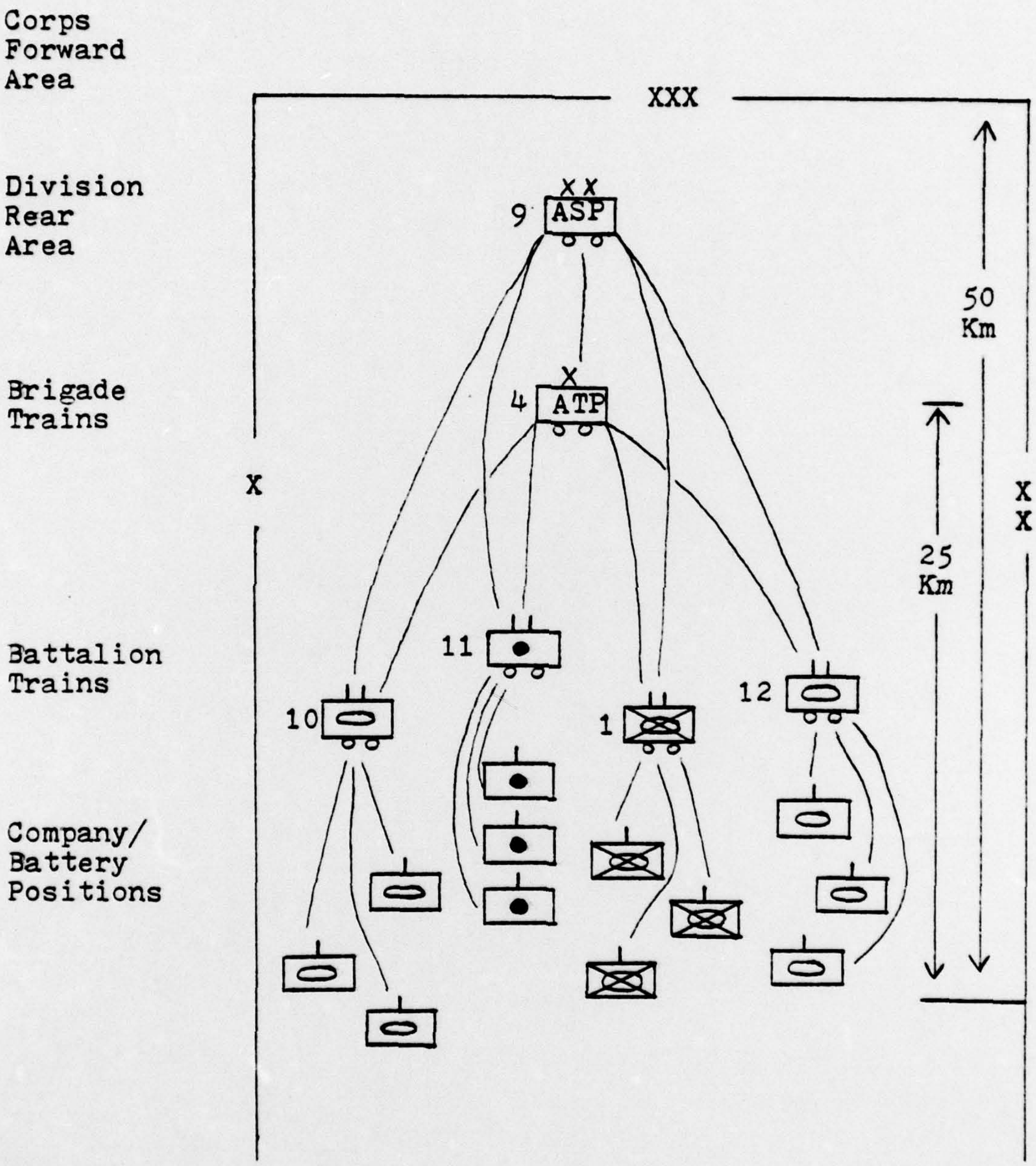
APPENDIX C

EXAMPLE NETWORKS

The ammunition and POL networks described in the example in Chapter IV are presented in this appendix. The number to the left of each box is the node number assigned for the example. The distances indicated are approximate and would vary depending on the tactical situation.

FIGURE 3

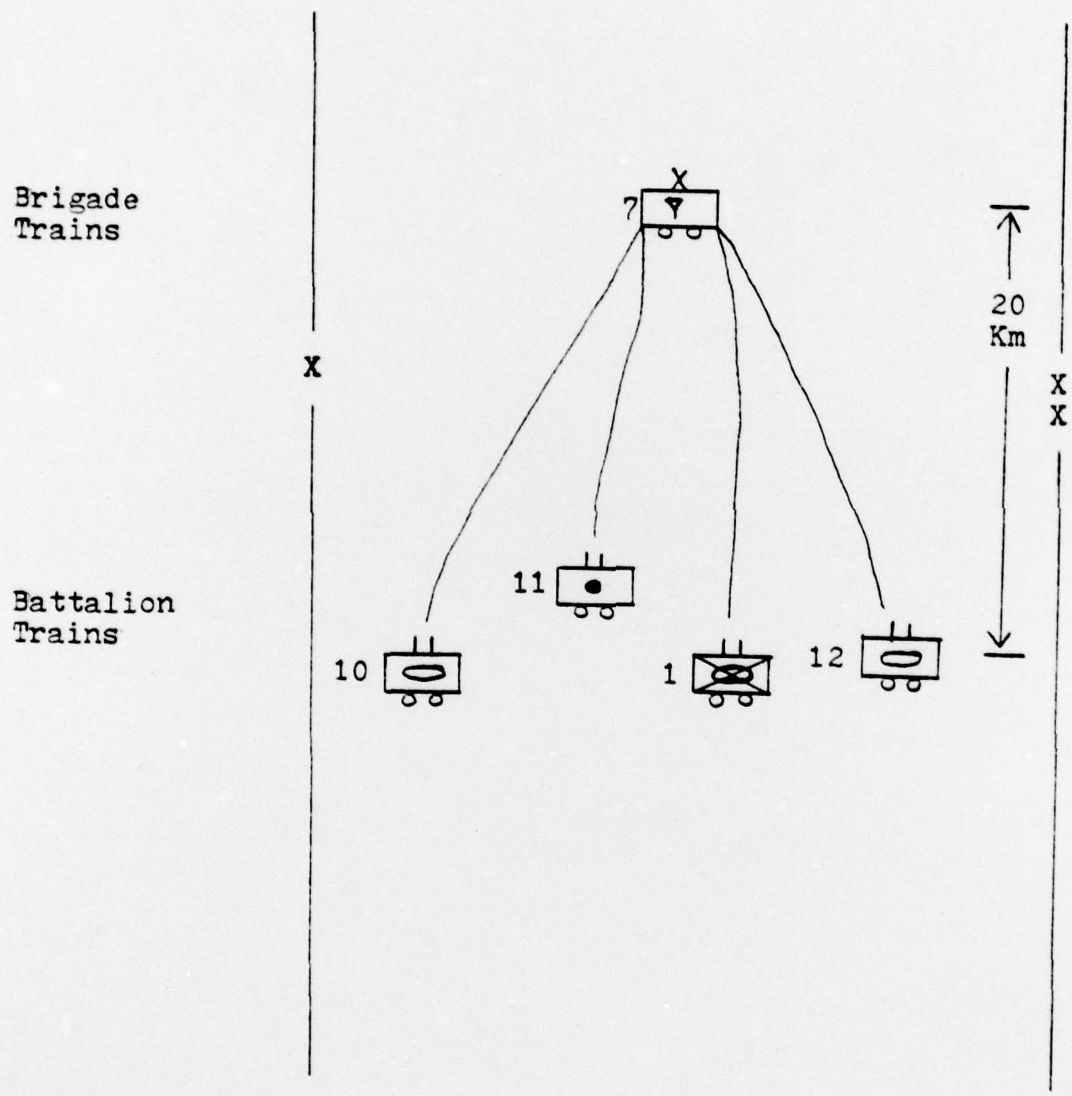
BRIGADE AMMUNITION SYSTEM



NOT TO SCALE

FIGURE 4

BRIGADE POL SYSTEM



NOT TO SCALE

APPENDIX D

EXAMPLE VEHICLE LISTING

This appendix contains a complete listing of the ammunition and POL carriers used for the example in Chapter IV. The first Armored Battalion and the Artillery Battalion carriers were listed in Chapter IV. Both Armored Battalions have the same number and types of vehicles but the index numbers are different.

The index subscript i was used for ammunition carriers (CC_i) and p for POL carriers (CCP_p). The carrier code letters are j for ammunition and q for POL. In general then,

$$CC_i = j \qquad CCP_p = q.$$

The specific carrier codes for ammunition carriers used in the example are:

j=1 8T truck;
j=2 1½T ammunition trailer.

The carrier codes for POL carriers are:

q=1 truck fuel servicing, GOER(2500 gallons);
q=2 tank and pump unit (two 600 gallon pods on a truck);
q=3 tank unit (one 600 gallon pod on a trailer).

The first Armored Battalion had five 8T trucks for ammunition carriers. Therefore, the carrier code for carriers 1-5 is one. The POL carriers are:

4 GOER's	q=1;
4 tank and pump units	q=2;
4 tank units	q=3.

The battalion identification number was one. Therefore, for ammunition carriers $i=1-5$, $BN_i=1$ and for POL carriers $p=1-12$, $BNP_p=1$. The Armored Battalion vehicles by index number and carrier code are:

AMMUNITION CARRIERS

$CC_1=1$
$CC_2=1$
$CC_3=1$
$CC_4=1$
$CC_5=1$

POL CARRIERS

$CCP_1=1$	$CCP_5=2$	$CCP_9=3$
$CCP_2=1$	$CCP_6=2$	$CCP_{10}=3$
$CCP_3=1$	$CCP_7=2$	$CCP_{11}=3$
$CCP_4=1$	$CCP_8=2$	$CCP_{12}=3$

The Artillery Battalion had thirty-six ammunition carriers ($i=6-41$) as follows:

18 8T trucks	$j=1$;
18 1½T ammunition trailers	$j=2$.

The battalion also had four POL carriers($p=13-16$):

2 GOER's	$q=1$;
1 tank and pump unit	$q=2$;
1 tank unit	$q=3$.

The battalion identification number was two. The battalion codes therefore are:

$BN_i=2$ for $i=6-41$;
$BNP_p=2$ for $p=13-16$.

The Artillery Battalion's vehicles by code are:

AMMUNITION CARRIERS

$CC_6=1$	$CC_{24}=2$
$CC_7=1$	$CC_{25}=2$
.	.
.	.
.	.
$CC_{23}=1$	$CC_{41}=2$

POL CARRIERS

$CCP_{13}=1$ $CCP_{15}=2$ $CCP_{16}=3$
$CCP_{14}=1$

The Mechanized Infantry Battalion had five ammunition carriers ($i=42-46$):

5 8T trucks $j=1$.

The four POL carriers ($p=17-20$) are:

2 GOER's	$q=1$;
1 tank and pump unit	$q=2$;
1 tank unit	$q=3$.

The battalion identification number was three. The battalion codes are:

$BN_i=3$ for $i=42-46$;

$BNP_p=3$ for $p=17-20$.

The battalion's vehicles by index number and carrier code are:

$CC_{42}=1$	$CCP_{17}=1$	$CCP_{19}=2$	$CCP_{20}=3$
$CC_{43}=1$	$CCP_{18}=1$		
$CC_{44}=1$			
$CC_{45}=1$			
$CC_{46}=1$			

The second Armored Battalion had five 8T trucks ($i=47-51$) for ammunition carriers. The POL carriers ($p=21-32$) are:

4 GOER's	$q=1$;
4 tank and pump units	$q=2$;
4 tank units	$q=3$.

Tha battalion identification number was four. The battalion codes are:

$BN_i=4$ for $i=47-51$;

$BNP_p=4$ for $p=21-32$.

The second Armored Battalion's vehicles are:

$CC_{47}=1$	$CCP_{21}=1$	$CCP_{25}=2$	$CCP_{29}=3$
$CC_{48}=1$	$CCP_{22}=1$	$CCP_{26}=2$	$CCP_{30}=3$
$CC_{49}=1$	$CCP_{23}=1$	$CCP_{27}=2$	$CCP_{31}=3$
$CC_{50}=1$	$CCP_{24}=1$	$CCP_{28}=2$	$CCP_{32}=3$
$CC_{51}=1$			

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